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A study of the effect of tension on the electrical resistance of alloys. II

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With 5 figures in the text

Introduction

A report is given of results of further measurements of the change of electrical resistance with elastic strain in alloys. The alloys investigated are characterized by a fairly low value of the temperature coefficient of resistance, which quantity has also been measured. Since, for a possible technical use of the alloys, a low thermoelectric power against copper is desirable, this quantity has also been measured for some of the alloys in the temperature range 20°—100° C.

1. Experimental arrangement

For the resistance measurements the arrangement described in (1) was used, with the exception that a Thomson double bridge was employed instead of the Wheatstone bridge. For the thermoelectric measurements a compensation apparatus was used. The thermostat used consisted of a wooden box covered on the inside with aluminum foil (0.01 mm thick) cut out in zig zag form and glued on the walls of the box. The box was heated by a current through the foil, and in this manner a very uniform temperature was obtained in the fairly large volume of the box. The temperature could be changed to any desired value by changing the applied electric power, and the equilibrium temperature was reached rapidly owing to the fact that radiation is the essential form of heat transport in this arrangement. The temperature measurements, which are not critical for samples with very low values of the temperature coefficient of resistance and thermoelectric power, were made with a mercury thermometer.

The alloys studied are given in Tab. 1. Fig. 1 a gives the resistance-stress curves for the Ag-Mn alloys investigated and Fig. 1 b the corresponding stress-strain curves. Owing to the elastic after-effect, the curves for increasing and decreasing load do not coincide exactly. The mean value from both is used in the calculation of Young's modulus.

In Fig. 2 the values of Young's modulus E, the resistance-stress coefficient a, the strain-gauge factor g and the resistance-temperature coefficient α are plotted versus concentration c of the alloys.

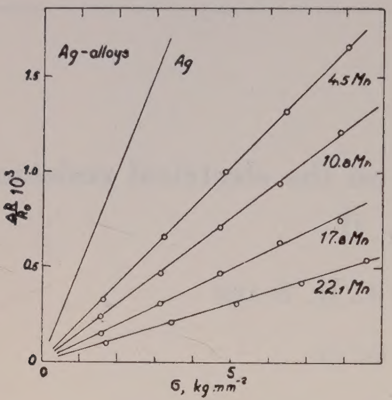

Fig. 1 a.

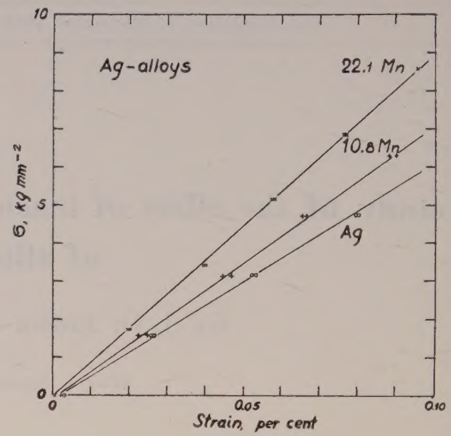

Fig. 1 b.

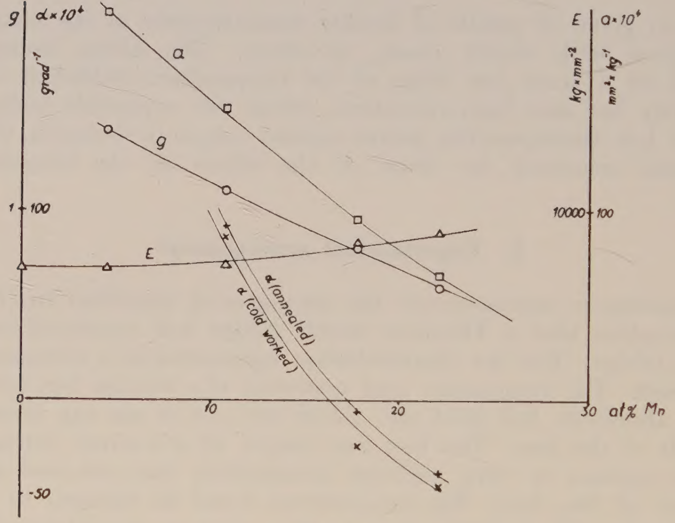

Fig. 2.

As is seen from the figure the temperature coefficient of resistance of the alloys is zero at about 17 at % Mn. The gauge factor $g = \frac{\Delta R}{R} : \frac{\Delta l}{l}$ has here a value of about 0.8, thus much lower than the corresponding value for constantan ($g \approx 2.05$). Nevertheless the Ag-Mn alloys may be of some interest for the practical task of finding materials for strain gauges suitable for special measuring problems. The Ag-Mn alloys have a very low thermoelectric power against copper, and a low value of Young's modulus compared with that of constantan. These properties are favourable for the use of the alloys for stress-strain measurements. The alloys are also very ductile.

Table 1

(The figures before the chemical symbols indicate the concentration c of the solutes in atomic percentage.)

Specimen	$\alpha \times 10^5$ degree^{-1}	$a \times 10^6$ kg^{-1} cm^2	$E \times 10^{-6}$ kg cm^{-2}	g	$e \times 10^6$ Volt degree^{-1}	$\varrho \times 10^6$ ohm cm	State of the specimen
Kanthal A	0.4	1.29	2.09	2.70	−2.8	140	
Ag alloys							
4.5 Mn		2.05	0.70	1.43	—	9.1	cold-worked
10.8 »	8.6	1.54	0.72	1.11	+3.0	19.2	» »
17.8 »	−2.4 (−5.5)[1]	0.96	0.84	0.80	+2.0	31.8	» »
22.1 »	−4.5 (−3.8)[1]	0.66	0.89	0.595	+2.5	43.1	» »
Au alloys							
Au	—		0.72	3.0	—	2.25	cold-worked
6.4 Cr	—	0.40	0.9	0.36	—	28.2	» »
9.0 »	—	−0.12	0.9	−0.11	−8.7	40.5	» »
10.4 »	—	0.441	0.96	−0.424	−9	46.9	annealed at 100° C
21.6 »	1	−1.57	1.03	−1.61	−6	90	» » »
7.3 Mn	—	0.61	0.89	0.54	—	19.5	cold-worked
27.3 Fe	—	2.08	1.04	2.0	—	77.6	» »
A 1[2]	−1	0.83	0.94	0.78	−7	43.0	» »
A 2[3]	3	0.81	0.9	0.73	−3	42.3	annealed at 100° C

[1] Annealed at 200° C.
[2] 90.88 Au 4.55 Cr 2.21 Mn 2.36 Fe.
[3] 88.66 Au 2.25 Cr 7.34 Mn 1.75 Fe.

The curve for values of Young's modulus, E, for the Ag-Mn alloys in Fig. 2 is of special interest. As can be seen, E increases with increasing concentration c of the solute. In this respect the Ag-Mn alloys resemble the Cu-Ni alloys. For the alloys of Cu and Ag with Si and Sn E decreases with the concentration of the solute (1).

The authors' value of Young's modulus for Ag ($E = 0.70 \times 10^6$ kg/cm^2) is lower than modern tabled values, e.g. Kohlrausch, Praktische Physik ($E = 0.80 \times$ $\times 10^6$ kg/cm^2). According to the authors' opinion the latter value is to be corrected.

The measurements on Kanthal A (Table 1) (a commercial alloy supplied by AB Hallstahammar, Sweden) show a low value of the temperature coefficient of resistance, a fairly low value of the thermoelectric power against copper and a high value of the gauge factor g. The resistivity of the alloy is also extremely high. ($\approx 140 \times 10^{-6}$ ohm cm). The alloy seems therefore suitable for strain gauges, but difficulties in soldering prevent its general use.

Finally the results of measurements on some Au alloys are given. The results are shown in Fig. 3 and Table 1.

It is interesting to note that the resistance-stress coefficient of the Au-Cr alloys assumes negative values when the Cr concentration is increased to a certain amount. These alloys have at high Cr concentrations a fairly low value of the temperature coefficient of resistance α (α being zero at about 7.2 at % Cr).

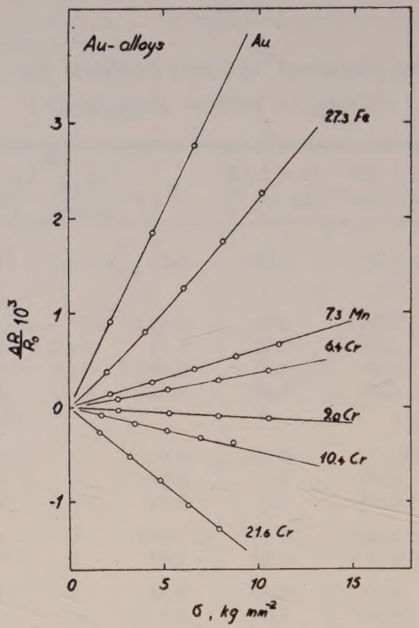

Fig. 3.

Their thermoelectric power against copper is lower than that of constantan but higher than for the Ag-Mn alloys. The alloy with 21.6 at % Cr shows a remarkably high negative value of the gauge factor g ($g = -1.6$). The properties of this alloy are such that it can be employed for strain gauges in special measuring problems.

Work on quartenary Au-Cr-Mn-Fe alloys has given the results shown in Table 1. As can be seen, no better material has been found than the alloys already described. The studies on these alloys are part of a more comprehensive investigation of resistance materials for other purposes, the results of which will be published later.

2. Discussion of the resistance-tension properties of alloys

By considering the change of volume involved in elastic deformation a general rule for the corresponding change of resistivity can be established, which is valid for the effect of tension and hydrostatic pressure as well. In an earlier paper one of the authors has shown that for the change of resistivity with pressure there exists a linear relationship between $\frac{d\varrho}{dp}$ (derivative of resistivity with pressure) and the concentration c of the added element in the alloy series (2). Results for dilute Cu, Ag and Au alloys showed increasing values of $\frac{d\varrho}{dp}$ with the concentration c in certain alloy series and decreasing values in others.

In the case of tension we have to consider $\frac{d\varrho}{d\sigma}$ instead of $\frac{d\varrho}{dp}$. As described in an earlier communication (1) this quantity can be obtained from the directly measured resistance-stress coefficients a. We have

$$\frac{d\varrho}{d\sigma} = \varrho_0 \left(a - \frac{1 + 2\mu}{E} \right)$$

where ϱ_0 is the resistivity at zero stress, E Young's modulus, and μ Poisson's ratio.

In Fig. 4 the values of $\frac{d\varrho}{d\sigma}$ and $\frac{d\varrho}{dp}$ according to the present and earlier measurements (1, 2) are given as a function of the resistivity increase ϱ_z for some alloy systems. In the cases where μ is not known for the alloys, the value for the corresponding pure matrix metal was used in the calculation. The characteristic feature of this diagram is that the slope of the straight lines obtained for a given alloy series has an opposite sign for the two kinds of elastic deformation. This means that the effect of deformation has the same sign if, in both cases, the change of resistivity is referred to the change of volume caused by the deformation. (Elastic deformation by tension is accompanied by an increase of volume, while deformation by pressure is accompanied by a decrease of volume). From the sign of the slope in Fig. 4 the sign of the corresponding coefficient for the resistivity dependence is obtained.

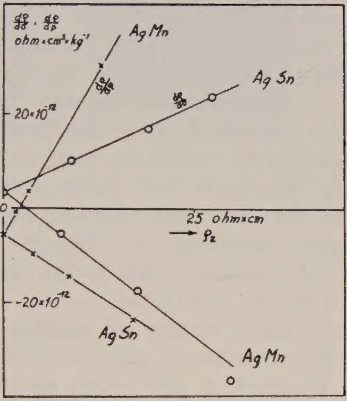

Fig. 4.

From these regularities we are also able to understand why alloys, such as manganin and the Ag-Mn alloys, which show a remarkably high positive value of the resistance-pressure coefficient, are characterized by a rather low value of the resistance-stress coefficient. In deformation by pressure the change in resistivity and the change of resistance owing to the geometrical change in the specimen add together, both effects having the same sign. In tension the change in resistance owing to the change in geometrical dimensions of the specimen is positive, while as Fig. 4 shows the deformation causes a decrease in resistivity in the cases where the resistance-pressure coefficient is positive (Ag-Mn). Here the total change is a difference between two terms, both of the same order of magnitude. An analogous reasoning holds true for alloys with a negative resistance-pressure coefficient. It follows that the resistance-stress coefficient of these alloys is fairly high, and an example is given by constantan, an alloy often used for strain gauges. The Cu-Si and Ag-Sn alloys also have fairly high resistance-stress coefficients (1), but they cannot find practical use as strain gauge material because of their high temperature coefficients of resistance.

Conversely, the regularities found allow certain conclusions about the resistance-pressure dependence of alloys to be drawn from resistance-tension measurements.

SUMMARY

The dependence of strain on resistance and some other physical properties have been studied for a number of alloys. Detailed studies have been made on the alloy series Ag-Mn and Au-Cr. The Ag-Mn alloys which are characterized by a high value of the resistance-pressure coefficient show no correspondingly high value of the resistance-stress coefficient. Analogous results are, according to earlier measurements, valid for manganin. The regularities found in this work, indicate that the fairly low value of the resistance-stress coefficient is a consequence of the fact that, deformation by tension is connected with an increase in volume, resulting in different signs for the change of resistivity and the change of resistance due to the change of geometrical dimensions of the sample of the alloys mentioned.

The work has also given some results of interest for the practical problem of finding alloys suitable for wire strain gauges. The Ag-Mn and Au-Cr alloys and the technical alloy Kanthal A are worth mentioning in this connection.

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